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ESSENTIAL CHARACTERISTICS OF THE STRUCTURE OF "PEARL LIKE" FLUCTUATIONS OF THE MAGNETIC FIELD IN GEOMAGNETICALLY CONJUGATE REGIONS

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ESSENTIAL CHARACTERISTICS OF THE STRUCTURE OF "PEARL-LIKE" FLUCTUATIONS OF THE MAGNETIC FIELD IN GEOMAGNETICALLY CONJUGATE REGIONS*

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by A. M. Borsukov &
Miss C. Poinsot

SUMMARY

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Numerical analysis has been applied to the study of rapid fluctuations of the Earth's magnetic field ("pearls"). We have studied both, the correlation between the oscillations themselves, and that between their envelopes:

1.- Comparison of the phases of two components, perpendicular to the same point (Lovozero, USSR) shows, that the oscillations of different frequencies, composing the beatings, have elliptical polarizations, of which the major axes are different.

2.- Study of the same components at two stations, distant by 1100 km (Lovozero and Borok, USSR), has shown that the two phenomena are in phase.

3.- When the same method is applied to registrations of two geomagnetically conjugate regions (Borok and Kerguelen), it is impossible to find any in-phase correlation between the two signals.

4.- There exists, however, a complete similitude between the envelopes of received oscillations in two geomagnetically conjugate regions, the only difference being a certain time lag between the two maxima, approximately equal to the half-period of repetition.

The results are still too scarce to allow for a theoretical explanation.

Author

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* Caractéristiques essentielles de la structure des oscillations en perles dans des régions géomagnétiquement conjuguées

I. - INTRODUCTION

Simultaneous registrations of the Earth's magnetic field were undertaken at Kerguelen Islands and in Soviet Union, at the beginning of 1964, between two geomagnetically conjugate regions. Phase comparisons were made at the Institute of Terrestrial Physics in Moscow; they concerned the registrations of the H_x- component at Kerguelen $(\Phi = 56^o S, \Lambda = 128^o E)$ and at Borok $(\Phi = 52^o N, \Lambda = 123^o E)$ and of two H_x-and H_y -components of Lovozero $(\Phi \doteq 62^o N, \Lambda = 127^o E)$ Indeed, whaterver the type of oscillations, the two components of the natural magnetic field seldom have anagous forms. This can probably be explained in the case of the so-called "irregular" disturbances by sharp variation in time of frequencies of observed oscillations, whereas in case of "pearls", or PC 1 according to the new classification [1], this is due to the existence of two or more waves of different frequencies, whose azimuths do not coincide. Although these wave have very close frequencies, they will be denoted in the following by the term "harmonic" *. These, two or three in number, were ascertained with the help of a sonograph-type of sepctrum analyzer [2, 3]. However, the sonograms obtained do not allow to determine the character of polarization of these "harmonics", so that for this study one applies a rather simple variant of correlation analysis.

II. - METHOD OF ANALYSIS

This analysis is based upon the hypothesis that the frequencies of harmonics are the same for each component. One may then represent these components by two functions X and Y, such as

$$X = a_x \sin(\omega_0 t + \alpha_x) + b_x \sin(\omega_1 t + \beta_x),$$
$$Y = a_y \sin(\omega_0 t + \alpha_y) + b_y \sin(\omega_1 t + \beta_y).$$

with

$a_x \neq a_y \neq b_x \neq b_y$	Amplitudes of harmonics
$\omega_0 \neq \omega_1$	Pulsations of Harmonics
$\alpha_x, \alpha_y, \beta_x, \beta_y$	Initial phases of harmonics

* The term "harmonic", which we use to avoid any confusion with the word "component", used elsewhere, denotes a harmonic oscillation and not an oscillation of multiple frequency of a fundamental.

One may notice that for $(w_0 - w_1)$ comprised between 0.8π and 4π rads^{-1} we find the pulsations "in pearls" usually observed and whose period is

$$T = \frac{2\pi}{\omega_0 - \omega_1}$$

varying between 2.5 and 0.5 seconds.

The correlation factor between the two components X and Y depends on the value of amplitudes $a_x a_y b_x b_y$. For an analysis interval equal to one or several recurrence periods and for in-phase harmonics $(\alpha_x = \alpha_y, \beta_x = \beta_y)$, it is

$$r = \frac{1 + \frac{b_x}{a_x}\frac{b_y}{a_y}}{\sqrt{\left(1 + \frac{b_x^2}{a_x^2}\right)\left(1 + \frac{b_y^2}{a_y^2}\right)}}.$$

But in the general case, all the initial phases are different $(\alpha_x \neq \alpha_y \neq \beta_x \neq \beta_y)$. The correlation factor then depends only on the ratios $\frac{b_x}{a_x}$ and $\frac{b_y}{a_y}$, but also on the differences of phase :

$$\Delta\alpha = \alpha_x - \alpha_y \quad \text{and} \quad \Delta\beta = \beta_x - \beta_y.$$

It is equal to :

$$r = \frac{\cos\Delta\alpha + \frac{b_x}{a_x}\frac{b_y}{a_y}\cos\Delta\beta}{\sqrt{\left(1 + \frac{b_x^2}{a_x^2}\right)\left(1 + \frac{b_y^2}{a_y^2}\right)}}.$$

The coefficient grows when the phase difference $\Delta\beta$ approaches zero (or 2π) for every value of $\Delta\alpha$ and when $\Delta\alpha$ approaches zero or 2π for every value of $\Delta\beta$. Thus, when the phase angles vary in time, the correlation function of functions X and Y offers a maximum when the two phase angles relative to a same harmonic are equal. To study this correlation function, we postulate :

$$\Delta\alpha_y = \omega_0\,\Delta t \quad \text{and} \quad \Delta\beta_y = \omega_1\,\Delta t.$$

In this case we have

$$r = r(\Delta t).$$

This correlation function depends on the ratio of frequencies ω_0 and ω_1. As an example, we plotted in Fig. 1 the curves $r = r(\Delta t)$ for

$$\frac{b_x}{a_x} = 0{,}5,$$

and

$$\frac{b_y}{a_y} = 8(\omega_0 = 2\pi,\ \omega_1 = 1{,}6\pi).$$

The initial phases of harmonics (these curves' parameters) are

$$\begin{aligned} &a)\ \Delta\alpha = 0,\quad \Delta\beta = 0,\\ &b)\ \Delta\alpha = 0,\quad \Delta\beta = \pi/4,\\ &c)\ \Delta\alpha = 0,\quad \Delta\beta = \pi/2. \end{aligned}$$

The envelope of the extreme values that the function of correlation can assume for a given value of the ratios $\frac{b_x}{a_x}$ and $\frac{b_y}{a_y}$, and for every value of frequencies is plotted in dashes.

b) In order to achieve this analysis, we utilize the ordinates of the registrations on paper (see Fig. 4)* taken at regular and equal time intervals Δt, for example, at the sixth of the oscillation period. The continuous curve obtained $r = r(\Delta t)$ and the sine curve $S(\Delta t)$. This is shown by a dashed line in Fig. 2. The easy transition from one curve to the other and the small experimental shifts justify these approximations.

III. - CORRELATION BETWEEN BOROK AND LOVOZERO

For Borok and Lovozero we computed the correlation functions between the two components H_x starting from registrations effected on 24 February 1964 between 09 02 hrs and 43.5 sec. and 10 30 hrs and 48 sec. The transit velocity is 5 mm per second. Figs 2a and 3a represent these correlation functions computed over time intervals of different durations. It may be seen from these figures :

– that the correlation function has a maximum maximorum for $\Delta t = 0$. Thus there is no phase lag between the received signals (within 0.1 sec. limits) despite the distance of 1100 km separating these stations.

– that the correlation function maximum is near 1 in the case of a single pearl (Fig. 2a) and decreases when the time interval increases (Fig. 3a). The first result means that the amplitude ratio of harmonics on the component H_x is the same at Lovozero and Borok. The decrease of the correlation factors as a function of time interval accretion, upon which analysis has bearing, is linked with the presence of an alien field in the vicinity of beat nodes, the signal not being there exactly zero, as may be seen in Fig. 4.

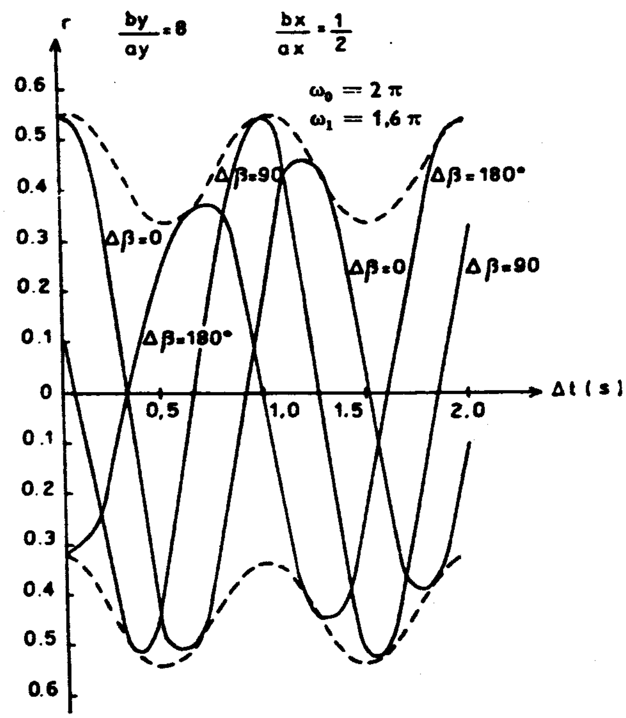

Fig. 1. - Theoretical correlation factor between the two components of an electromagnetic field composed of two waves, having different frequencies and initial phase angles.
(See text for definition of annot.)

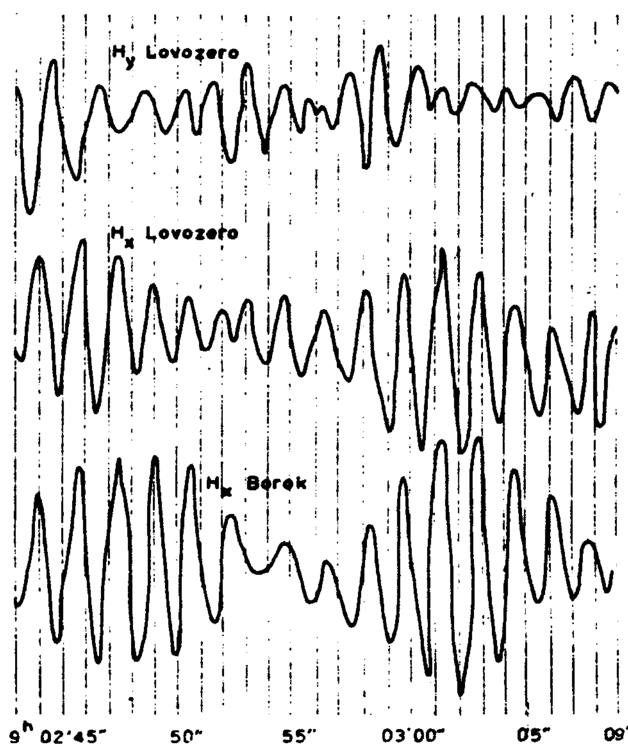

Fig. 4. - Reproduction of the Registrations of Borok and Lovozero.

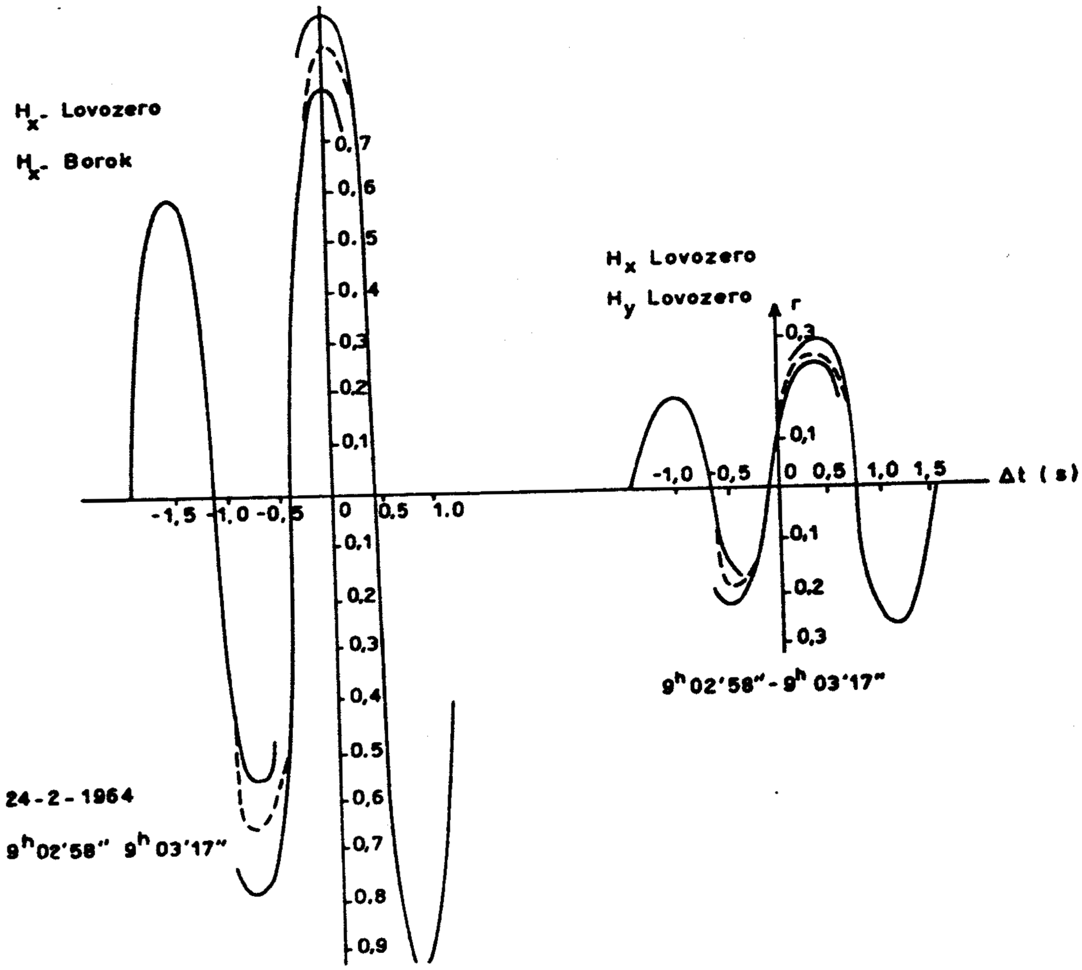

Fig. 2. - Experimental correlation factor between : a) the same component at two points distant by 1 100 km; b) two orthogonal components at the same point.

IV.- CORRELATION
BETWEEN TWO PERPENDICULAR COMPONENTS

Similar calculations were effected for two perpendicular components H_x and H_y of Lovozero during the same periods. The curves obtained are represented in Figures 2b and 3b. They show :

– that there is no maximum for $\Delta t = 0$. Thus, the harmonics composing the Lovozero beatings, are polarized elliptically.

— that the maxima of the correlation factors are considerably smaller than the unity; the ellipses' major axes are oriented at various directions and it is possible that the eccentricities may also be different. Moreover, the noncoincidence of amplitude maxima shows the variation in time of the parameters of polarization ellipses.

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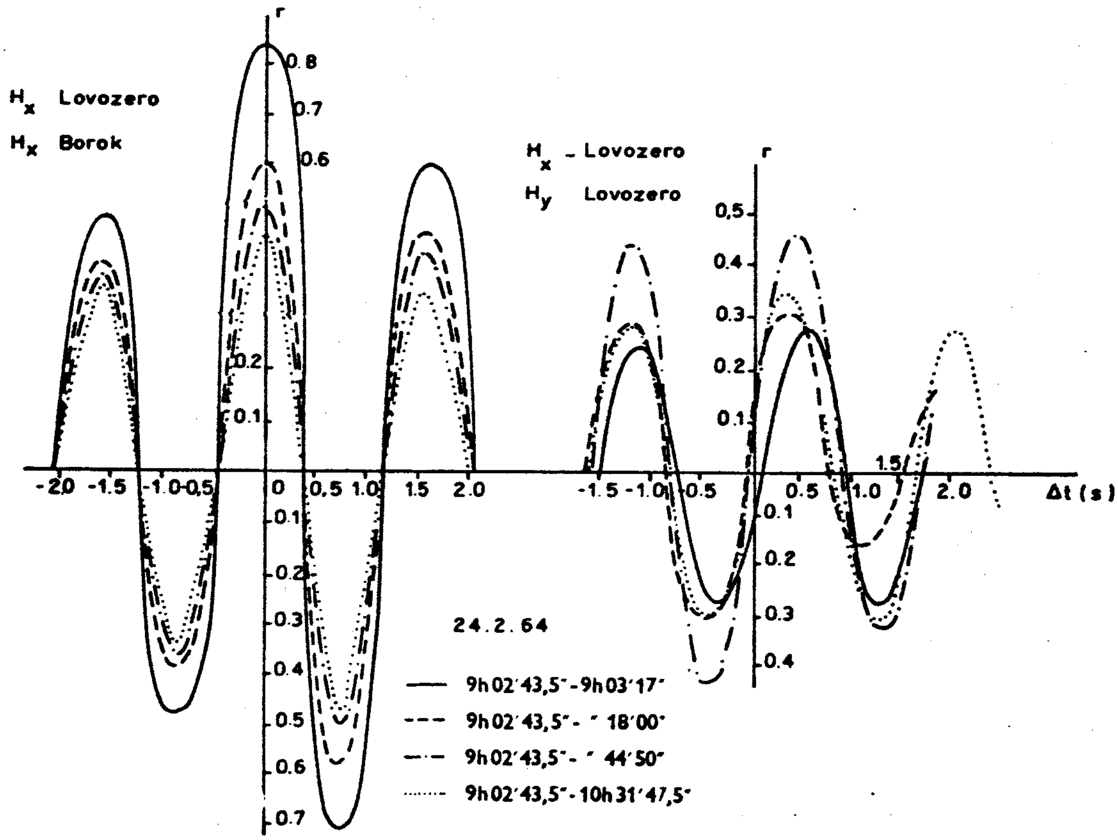

Fig. 3. - Experimental correlation factor between :
a) the same component at two points distant at 1100 km;
b) two components, orthogonal at the same point.

V. - CORRELATION BETWEEN TWO CONJUGATE ZONES

V-1 Oscillations

The same method has been applied to registrations at Borok and Kerguelen, stations situated in regions geomagnetically conjugate.

a) The oscillation periods were determined with a precision to 0.1 sec. by calculating for each of the points the autocorrelation function for the time interval from 09 30 hrs 19" to 09 30 hrs 50 seconds of 24 February 1964. One may see in Fig. 5 that the maxima of these two functions take place for the same value $\Delta t = 1.7$ sec, which is the dominant period of oscillations.

b) The correlation factors between the components H_x at Kerguelen and at Borok over the time interval from 09 16 hrs 29 sec. to 09 18 hrs 00 sec. of 24 February 1964 do not allow to determine the phase difference of oscillations. Indeed, the correlation factors obtained are always small (± 0.1 to ± 0.2). Thus, it seems that there is no correlation of phase between the oscillations received at two conjugate points. However, the analysis period is too short for that conclusion to be accepted as final.

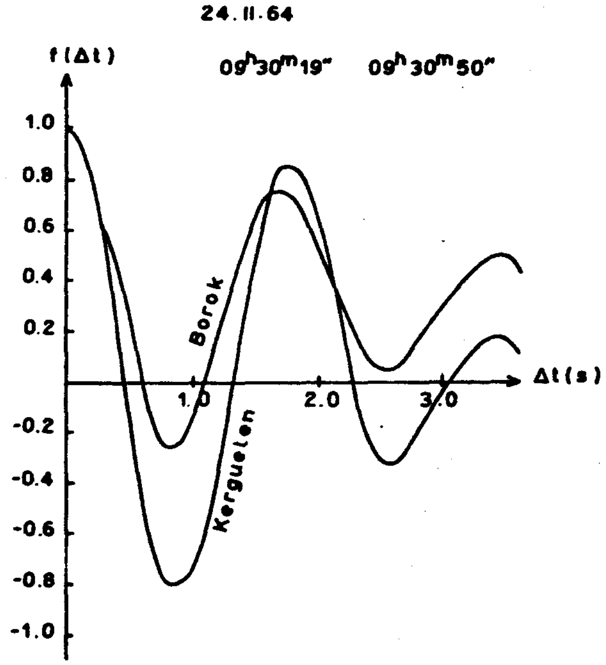

Fig. 5. - Autocorrelation functions of signals at Borok and Kerguelen

V-2. - <u>Trains of Oscillations</u>.

The period and phase determinations of "trains of pearls" in conjugate zones is linked with the explanation of the mechanism of pearl generation and propagation [5]. We just saw that the phase correlation of the oscillations themselves does not provide any positive result. But the same method can be applied to the envelope of the "train of pearls" which was done.

a) Fig. 6b represents the autocorrelation functions $f(\Delta t)$ for envelopes of the trains of pearls of 17 February 1964 from 22 58 to 23 10 hours, registered at Borok and Kerguelen, They determine the periods of recurrence, all equal among themselves, and of 120 seconds' value.

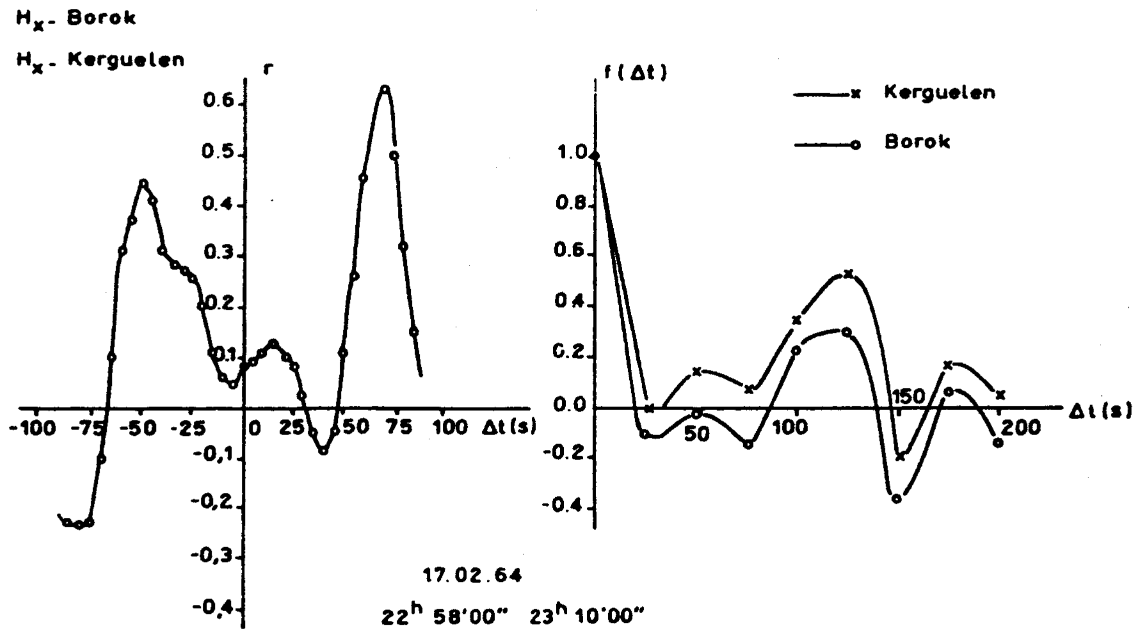

Fig. 6. — Fonctions de corrélation (fig. 6a) et d'autocorrélation (fig. 6b) des enveloppes des signaux reçus à Borok et Kerguelen, le 17 février 1964.

Fig. 6.- Correlation functions (fig. 6a) and autocorrelation (fig. 6b) of envelopes of signals received at Kerguelen on 17 Febr. 1964.

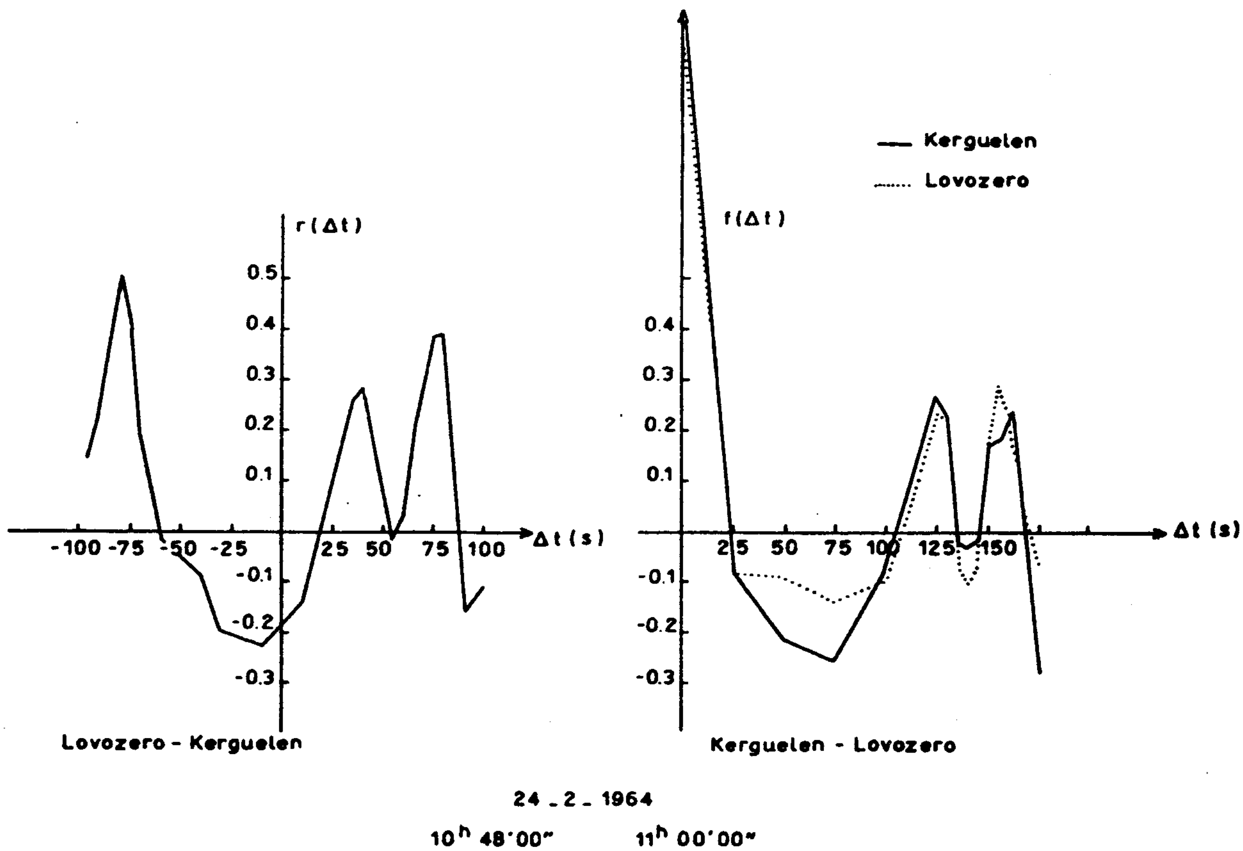

Fig. 7. — Fonctions de corrélation (fig. 7a) et d'autocorrélation (fig. 7b) entre les enveloppes des signaux reçus Lovozero et Kerguelen le 24 février 1964.

Fig. 7. - Functions of correlation (fig. 7a) and of autocorrelation (Fig. 7b) between the envelopes of signals received at Lovozero and Kerguelen

b) The correlation function was computed for the envelopes of the same trains of pearls (Fig. 6a). There is no maximum for $\Delta t = 0$. However, the presence of two very clear maxima on either side of $\Delta t = 0$ again indicates the equality of repetition(recurrence) at two stations and the position of these maxima allows to determine the dephasing between the trains. In this case, the asymmetric shape of the correlation function is evidence that a train of pearls appears at Kerguelen 70 seconds after the corresponding train at Borok, and that this phenomenon recurs 50 seconds later at Borok. This, incidentally, does not in any way oppose the conservation of periods at both stations. This asymmetry appears also in the results of analysis by means of a sonograph, though it is not mentioned by the authors, but the precision of measurements by that method is far more uncertain than those of the correlation method [7].

c) The same analysis was carried out on pearls registered on 24 February 1964 from 10^{48} to 11^{00} hours at Lovozero and Kerguelen (see Fig. 7 b), as for this example, the autocorrelation functions are more similar at these two stations than between Kerguelen and Borok. This shows that notion of magnetic conjugation is subject to variations in time for this type of phenomena too, which it would be interesting to study.

The existence here of a symmetric signal (dephasing exactly equal to half repetition period – here of 155 seconds) and of an asymmetric one is indicated more clearly in the Fig. 7 a.

VI. - CONCLUSION

The existence of a phase displacement between the trains of pearls has been recently ascertained experimentally [3], [5], [6]. But it would be necessary to verify the noncorrelatiom of oscillations themselves for conjugate zones (See V-1 b). It should also be mentioned that the asymmetry chara/cteristics that emerge through this method of analysis cannot be generalized over two examples. Thus an aggregate theory can not be elaborated on the basis of these partial results.

* * *

Follows a vote of thanks.

THE END

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